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THE STUDY OF THE INTERACTION OF INTENSE PROSECOND LIGHT PULSE WITH MATERIALS

A QUARTERLY TECHNICAL REPORT

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Quartely Techni cal Report

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Quarterly Technical Report

1. Introduction:

~~This~~ project covers the general subject of the interaction of the picosecond pulses with matter. Among the specific tasks proposed are the study of the optical harmonic generation with picosecond pulses and the measurement of the short pulses with nonlinear method. These will be the main topics of investigation for the current year.

Recently there has been considerable interest for measuring picosecond optical pulses with various techniques. There are advantages as well as shortcomings associated with each method. We have contributed to this field by introducing a new technique for picosecond pulse measurement. This new method utilizes the unique polarization properties of optical third harmonic generation in a phasematchable dye solution. We have observed for the first time a pulse width at half-maximum for a neodymium-glass mode-locked laser which is less than 0.73 picosecond. [1] Our observation also suggests that the light pulses from a neodymium-glass mode-locked laser may consist of one or more subpicosecond spikes superimposed on a wide background of several picoseconds. This is a significant result and one would like to check the measurement by using other techniques. On the other hand, there is shortcoming on the third harmonic measurement technique, namely, one requires many laser firings to obtain the pulse width. Based on this, we have started to look for other nonlinear effect for the pulse measurement. One of the new effects which does not utilize photographic detection nor photo-electric detection is the effect of two-photon induced photo-conductivity in semiconductor. If this effect is appliable to the picosecond pulse width measurement, it will be feasible in the future to construct an electronic device which will measure the picosecond pulse in a single laser firing and with digital readout. Thus we have picked, as our starting poing for this project, the study of two-photon induced conductivity in GaAs sample with the excitation light pulse from the Q switched neodymium-glass laser.

In section II we shall outline the theory of two-photon photoconductivity. The experimental detail and preliminary result of measurement are discussed in section III. In section IV, we conclude with the discussion of some of the experiments that will be carried out immediately.

II Two-photon Conductivity in Gallium Arsenide

With the advent of the laser, investigation of photoconductivity is no longer limited to low intensity light excitation. A number of workers have investigated photoconductivity by using gaint laser pulses. With such intense light beam, electrons and holes can be created by photons of energy less than the band-gap energy of the semiconductor-by two photon or multiphoton excitation process. Such experiment will yield valuable information about the inpurity levels, recombination mechanism and the behavior of non-equivalence charge carriers in the semiconductor. Gallium Arsennide is chosen because it is a direct band-gap material whose forbidden energy gap is about 1.5 ev. The O-switched newdymium-glass laser is used because its beam has photon energy of 1.17 ev. Thus the change of conductivity is due to two-photon process. Recently Yee (2) has calculated the two-photon conductivity in GaAs and Basov et-al (3)have derived for the intensity of light through a thickness of x centimeters of the crystal via two-photon process as

$$I(x) = I_o (1 + 2 \hbar \omega A_o I_o x)^{-1} \tag{1}$$

where $\hbar\omega$ = energy of light photon

I_o = incident light intensity

and A_o = a constant dependent on the band structure of GaAs

In two-photon process the generation rate of the carrier is given by

$$F(x) \approx A_o I^2 (x) \tag{2}$$

Using equation (2), Yee has solved the steady state carrier concentration P (x) from solving the differential equation

$$D_p \frac{\partial^2 P}{\partial X^2} - \frac{P}{\tau} = \frac{-A_o I_o^2}{(1 + 2\hbar\omega A_o I_o x)^2} \qquad (3)$$

Knowing the concentration, he is able to derive an expression for the equilibrium two-photon conductivity as

$$\Delta G = \frac{\alpha I_o^2 L A_o}{D\lambda^2 (1 + \beta L)} \quad \frac{2 V_s I_o^2 A_o \alpha e^{-2L/2}}{D\lambda^2 [(\lambda + V_s) - (\lambda - V_s) e^{-\lambda L}]} \times$$

$$\int_o^L \frac{\cosh \lambda (\frac{L}{2} - x)\, dx}{(1 + \beta x)^2} \qquad (4)$$

where $\alpha = \frac{c}{a} q (\mu_e + \mu_h)$

$\lambda = (D\tau)^{-1/2}$

$\beta = 2\hbar\omega A_o I_o$

D = diffusion length

τ = carrier lifetime

μ_e = electron mobility

μ_h = hole mobility

q = electronic charge

L = crystal thickness

c = width of crystal

α = length of crystal

$V_s = V'_s / D$

V_s = recombination velocity at surface

This expression shows that in general the photoconductivity induced in a crystal by two-photon excitation is strongly dependent on the crystal's surface-recombination velocity and on its thickness. For a particular sample, one can obtain a curve which describes equation (4). This is shown in Fig. 2 for the sample we use and will be discussed in detail in the next section.

III Experimental Method and Results

A dye Q-switched neodymium-glass laser was used to provide the excitation source. The output beam of the laser was directed to the sample which was a piece of GaAs single crystal. The crystal was of size 1.5 cm x 0.5 cm x 0.028 cm (a x c x L). The sample was n-type with carrier concentration of $10^{14}/cm^{3}$. Ohmic contact was achieved by alloying Ge and Au to the ends of the sample. A D.C. bias voltage of 1.5 volts was employed to sweep the photo-generated carrier across the sample and thus contributing as photocurrent which was allowed to flow through a series resistor. The voltage across this resistor was picked up and displayed on a dual beam scope which also displayed the laser output. The signals from the resistor were time correlated to the laser pulses. Further more when no bias was applied the signal disappeared. This showed that the signal was due to the change of photo-conductivity and not due to photovoltaic effect. Data has been taken with varable laser intensity by inserting different neutral density filter. The measured photo-conductivity was plotted against the relative laser intensity in a log-log scale as shown in Fg. 1. The slope of the resulting graph was approximately 0.6. Using Yee's expression (eq. 4), the theoretical curve was computed for the crystal thickness of 0.028 cm. In computing the expression we have estimated from the carrier concentrations of the sample and the measured relaxation time of the signal the value of λ 8 0 cm^{-1}, with the condition $V_s >> \lambda$ satisfied. Note that in Fig. 2 the theoretical curve has an average slope of 0.7 for laser power density in the range of 10 to 100 MW/cm^{2}. This number compares favorably with the estimated laser power density used in this experiment.

IV. Discussion and Future Plan

The intensity dependence of the conductivity on laser power has been measured in this preliminary run to be less than unity is somewhat surprising. Normally one would expect a slope two dependent for the two-photon induced conductivity effect. This discrepency is due to the negligence of the recombination process. By careful measurement one should be able to deduce information on recombination and relaxation. As suggested by the theory, it would require either a thin sample or low excitation level to achieve the slope two dependence which may lead to a new technique for measuring the picosecond pulse with. Works now underway are oriented toward such direction.

References

(1) R.C. Eckardt and C.H. Lee, "Optical Third Harmonic Measurements of Picosecond Light Pulses", Appl. Phys. Letters, Vol 15, 425 (1969)

(2) J.H. Yee, "Calculation of Two-Photon Conductivity in Semiconductors", Appl. Phys. Letters, Vol. 12, 193 (1969); Phys. Rev., Vol. 186, 778 (1969).

(3) N.G. Basov, A.Z. Grasyuk, I.G. Zubarev, V.A. Katulin and O.N. Krokhin, Soviet Phys. JETP Vol. 23 366 (1966)

Figure Caption

Figure 1 Measured conductivity change as a function of relative laser intensity.

Figure 2 Theoretically predicted conductivity change as a function of laser intensity for sample of 0.028 cm thick.

FIG. 1

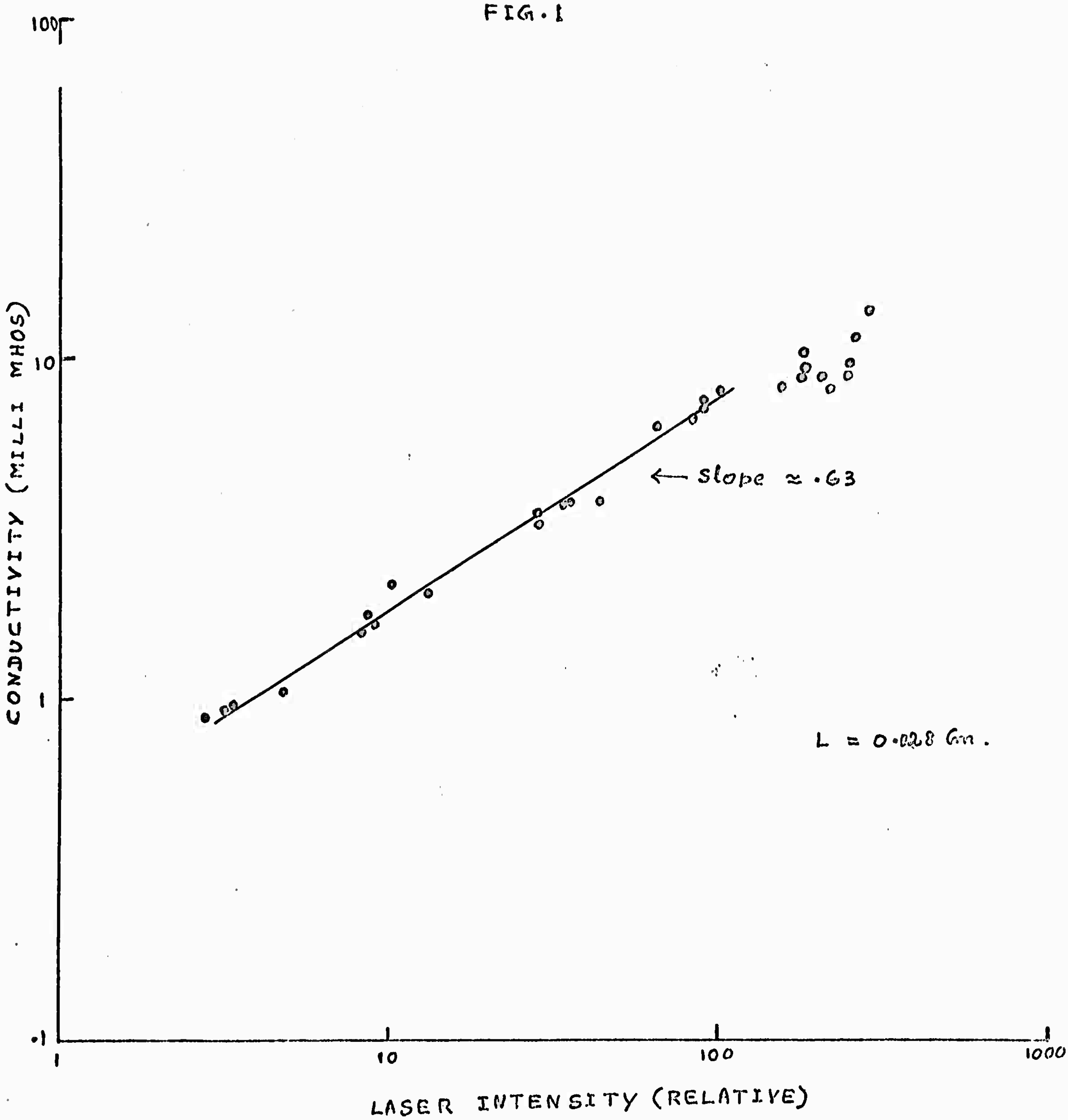
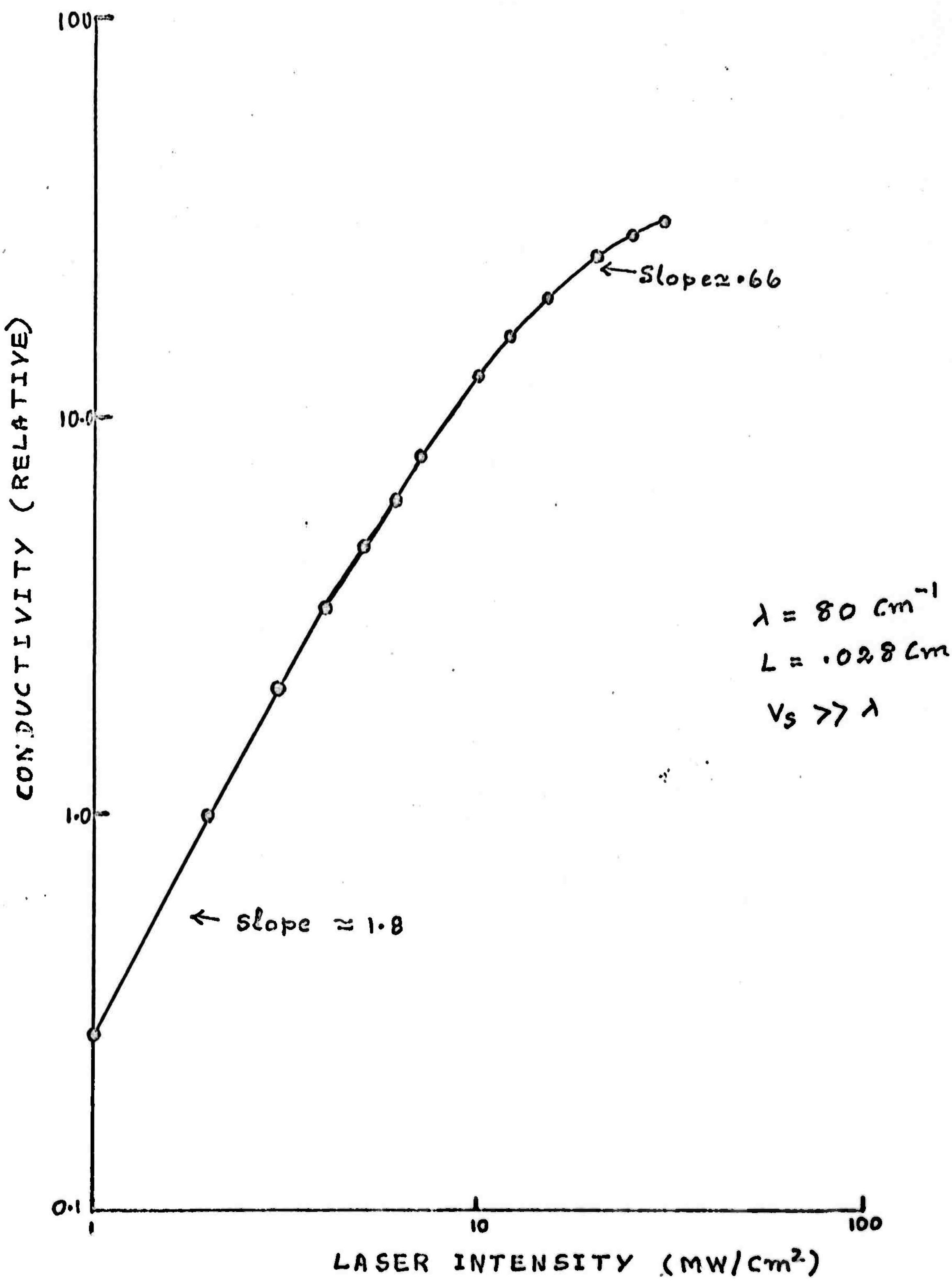

100
10
1
·1
1
10
100
1000
CONDUCTIVITY (MILLI MHOS)
LASER INTENSITY (RELATIVE)
← slope ≈ ·63
L = 0·028 Cm.

FIG. 2


100
10.0
1.0
0.1
1
10
100
CONDUCTIVITY (RELATIVE)
LASER INTENSITY (MW/cm²)
← Slope ≈ .66
← Slope ≈ 1.8
λ = 80 cm⁻¹
L = .028 cm
Vs >> λ